4. ENABLING TECHNOLOGIES

A. Improved Friction Tests for Engine Materials

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Objectives

- Develop a realistic, engine-correlated laboratory-scale test method to be used in selecting diesel engine piston ring and liner materials and work with ASTM, through an industry advisory group, to establish it as a standard practice.
- Investigate the effects of oil condition [new versus engine-conditioned (EC) lubricants] on the ability of the new test method to detect small friction and wear behavioral differences in engine materials in a repeatable manner.

Approach

- Review and critique past attempts to develop laboratory tests for piston ring and liner materials.
- Develop a testing protocol for friction and wear in reciprocating, lubricated contacts that simulate key aspects of the diesel engine environment.
- With the assistance of NIST, develop a fluid that simulates the effects of EC oil on the friction and wear response of candidate materials.
- Work with ASTM, through Committee G-2 on Wear and Erosion, to develop and approve a standard practice for conducting laboratory-scale piston ring and liner friction and wear tests.

Accomplishments

- Published a report describing and critiquing past efforts to develop engine-correlated laboratory-scale tests for materials and lubricants proposed for use in both spark-ignition and diesel engines.
- Established an ASTM task group on ring and liner wear within Committee G02.40 on Non-Abrasive Wear. Populated the task group with representatives from diesel engine companies, automotive companies, testing machine manufacturers, oil companies, government laboratories, and universities.

- Developed and published a technique for effectively simulating the surface finish of cast iron cylinder liner bores on simple test coupons.
- Obtained samples of oils run in standardized engine tests. These well-characterized test oils will be used to evaluate the ability of the new test to delineate lubricant condition.
- Prepared a draft standard practice for ASTM subcommittee review.

Future Direction

- Modify the draft ASTM standard practice as needed, based both on advice from the task group and on new laboratory results. Conduct tests in well-characterized engine test oils to evaluate the sensitivity and repeatability of the proposed method.

Introduction

Friction in moving parts robs engines of useful energy and lowers the vehicle's fuel economy. Depending on engine speed, the piston ring and liner system in an internal combustion engine can account for over 50% of the total engine frictional losses. New materials, lubricants, and coatings offer the potential to reduce frictional losses; but the development cost for these materials can be high, especially when full-scale engine tests are involved. Smaller-scale, simulative laboratory tests are an attractive alternative, but they can be useful only if their results correlate well with the materials' performance in real, fired engines.

Truck engine manufacturers and designers need more accurate and cost-effective laboratory screening methods for materials and lubricants. That need was placed high on the industry priority list in the recent DOE/OHVT multi-year plan in friction and wear.

The design of cost-effective laboratory-scale ring and liner simulations is not trivial. Improperly designed simulations can produce misleading results. Materials and lubricants must be induced to react in tests as they would in actual service. Tests should enable the ranking of alternative materials and lubricants in the same order of merit that they perform in service. That requires identifying the major influences on friction and wear behavior and controlling them in the laboratory.

ASTM is an international organization that develops consensus material testing standards. By working through ASTM Committee G-2, Oak Ridge National Laboratory (ORNL) is leveraging its efforts with those of other experienced testing professionals.

In FY 2001, key elements required for effective ring/liner simulation were identified. In FY 2002, the effort was focused on building an industry advisory group and involving ASTM. In FY 2003, friction and wear tests were conducted in new and used engine oils to refine the test methodology and prepare it for the rigorous ASTM standardization process.

Subtleties of Lubricated Testing

Obtaining correlated, repeatable friction and wear test results is much more complex than most people realize. The same combination of materials can produce different friction and wear results when rubbed together using different speeds, pressures, temperatures, motions, and lubricants. Therefore, it was necessary to consider all the possible influences of these factors in developing a laboratory test that effectively ranks materials and lubricants as they would be ranked in more expensive, full-size engine tests. For example, a shaft that always turns in one direction will not necessarily wear at the same rate as a shaft that oscillates back and forth under otherwise similar conditions.

Surface Finish

Friction and lubrication behavior depends on the surface finish, particularly in combustion engine cylinders. The direction and height of the finishing marks affects lubricant flow, fluid retention, and the traction between the surfaces. A special method was developed to prepare cylinder-like grinding patterns on cast iron coupons that can serve as test specimens. The methodology and the data that validated it were published in the 2001 proceedings of the Internal Combustion Engine Division of the American Society of Mechanical Engineers (ASME). Table 1, taken from that publication, shows that reciprocating sliding tests with new and used oil produced similar friction coefficients for a production Caterpillar C-15 diesel engine cylinder surface and for a surface that was simulated using the ORNL finishing technique.

Table 1. Comparison of friction coefficients (μ) for actual versus simulated cylinder liner surfaces[a]

Lubricant	Production liner (μ)	Simulated liner (μ)
None	0.287	0.292
Fresh 15W-40 diesel oil	0.068	0.069
Used (diesel-engine-tested) oil	0.061	0.070

[a]Type 440C stainless steel sphere sliding on test surfaces under 5 N load, 6 mm stroke, and 2 oscillations per second.

Running-in and Alignment

The test-to-test repeatability of friction and wear data depends on reproducing the same geometric fit between test surfaces every time. That requires excellent mechanical alignment, supplemented by an effective running-in procedure. Both aspects were addressed in this work. Dr. John Truhan, Jr., of the University of Tennessee developed a practical method to run-in the surfaces to enable a good initial fit.

In addition, there is a need to be able to calculate the volume of wear that occurs on curved surfaces such as piston rings and liners. Dr. Jun Qu, an Oak Ridge Associated Universities post-doctoral fellow, developed an analytical wear model to enable the more precise calculation of piston ring wear scars that have compound curvatures.

Oil Condition

Previous DOE-sponsored research at Cummins Engine Company indicated that fresh and EC oil can make differences in friction and wear of coatings for engine materials. Therefore, it was important in this work to identify the type of used oil or EC lubricant surrogate that could be used in a standard test for candidate ring and liner materials and surface treatments. Figure 1 shows the effect of applied test load on the wear rates (µm/h) for chrome-plated diesel engine piston rings sliding against cast iron liner materials. The cast iron was prepared to simulate cylinder bores using the finishing method noted earlier. Used diesel engine oil from a commercial engine test, heated to 100°C, was the lubricant. The ratio of liner wear to ring wear is about 5:1, higher than the ratio expected in engines. The reasons for that difference are known and can be accounted for in adjusting the test data to correspond better with engine wear data.

Specimens of five standard engine test oils (used) were obtained from Southwest Research Institute, and fleet-tested oils were obtained from Dr. J. Perez at Pennsylvania State University. Each will be analyzed and subjected to the proposed testing protocol to determine the method's ability to detect differences in the oil condition. Recommendations will then be made as to which oil or formulation should be used in order to obtain repeatable material screening results.

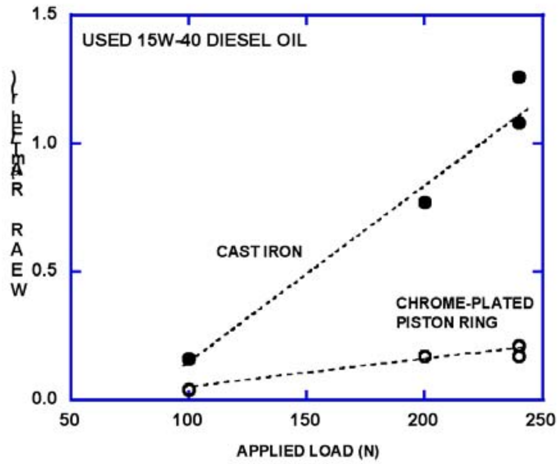

Figure 1. Effects of test load on the wear of piston ring and liner materials in hot used engine oil. Reciprocating tests used an 8-mm stroke length and a frequency of 10 cycles per second.

Development of a Standard

A draft standard has been prepared using the form and style prescribed by ASTM. It has been circulated for comment among the members of the task group on ring and liner wear, established by ASTM Committee G02.40 Subcommittee on Non-Abrasive Wear. A revised draft, based on industry comments, will be submitted for initial balloting at the fall 2003 ASTM committee meeting. It will also be presented for discussion in December 2003 at a joint ASTM D-2 (Lubricants) and G-2 (Wear and Erosion) workshop on new test methods. Undoubtedly, the test method will continue to evolve with input from the broader technical community. Depending on ballot results, it may require several balloting cycles to produce the approved, consensus-based standard.

Conclusions

Considerable progress has been made in developing a standard practice for lubricated diesel engine piston ring and liner materials testing. Past test methods have been reviewed, and new methods have been developed to prepare simulated lining surfaces, analyze complex wear patterns, align test specimens, and run-in the surfaces to improve test repeatability. More work is needed to identify the preferred EC lubricants to enable effective material screening. The ASTM review and consensus standardization process is under way with the preparation of a draft standard practice for ring and liner friction testing.